On the Positive Parity States of ^{19}F

By

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The calculation of rotation particle coupling has been done for the low-lying and positive parity states of ^{19}F. The level orders attributed to the $K=1/2$ and $3/2$ bands are computed, in which the moments of inertia are chosen as different values. The level energies up to about 5 MeV excitation can be fitted with the observed levels more satisfactory than others.

1. Introduction

The low-lying and positive parity levels of ^{19}F have been studied by using various models and their static and dynamic properties have been discussed.

In the harmonic oscillator shell model, these levels have been attributed to the composition of an ^{16}O core (closed 1s and 1p shells) and three outer nucleons in the (2s, 1d) shell. Elliott and Flowers[1)] and Redrich[2)] have introduced the interactions among the extra-core nucleons by a variational method and compared the calculated values with the observed level energies of positive parity.

By using strong coupling model, Paul[3)] has shown that these levels of ^{19}F can be understood by a mixing of its rotational bands. He also found a remarkable similarity between the strong coupling interaction and the prediction of the spherical shell model which included a configuration mixing.

This similarity has led to the further work by Elliott[4)]. He used the SU_3 classification for the shell model states to yield collective characteristics, and obtained the general relationship between collective and independent particle motions in the nucleus.

The low-lying states of positive parity have been discussed by Chi and Davidson[5)] applying an asymmetric core rotator model. Wildermuth *et al*[6)] have also discussed the levels by a cluster model. They derived the positive and negative parity states by $^{16}O+t$ and $^{15}N+\alpha$ clusters respectively. This work has been extended by Arima *et al*[7)].

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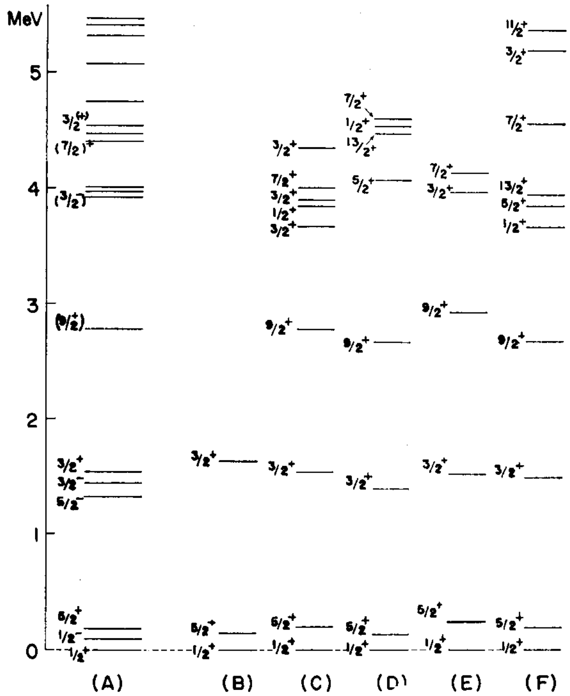

Fig. 1. A comparison of the observed energy levels of ^{19}F with those calculated by various authors. (A) observed, (B) by Redrich, (C) by Chi and Davidson, (D) by Arima *et al*, (E) by Paul, (F) by Elliott and Flowers.

The level spectra obtained by these authors are presented in Fig. 1. It is seen that the calculated levels do not always coincide with the experimental results, and therefore further interpretation would seem to be neccessary. In this paper, an improved calculation based on the strong coupling model is described.

2. Rotational model calculation of ^{19}F

According to Nilsson model[8], a rotational band attributed to $K=1/2$ (orbit 6) is expected in ^{19}F nuclear levels, because the spin and the partiy of the ground state have been assigned to be $1/2^+$. The energy spectrum of $K=1/2$ rotational band can be calculated by adopting the reasonable values of decoupling parameter and moment of inertia. They are estimated from the Nilsson wave function and the first excited states of neighboring even-even nuclei, respectively. Though the level order derived is correct, the level spacing becomes much larger than that observed.

The next rotational band is $K=3/2$ (orbit 7) which is about 3 MeV higher with respect to the $K=1/2$ band. These levels are shown in the left of Fig. 2.

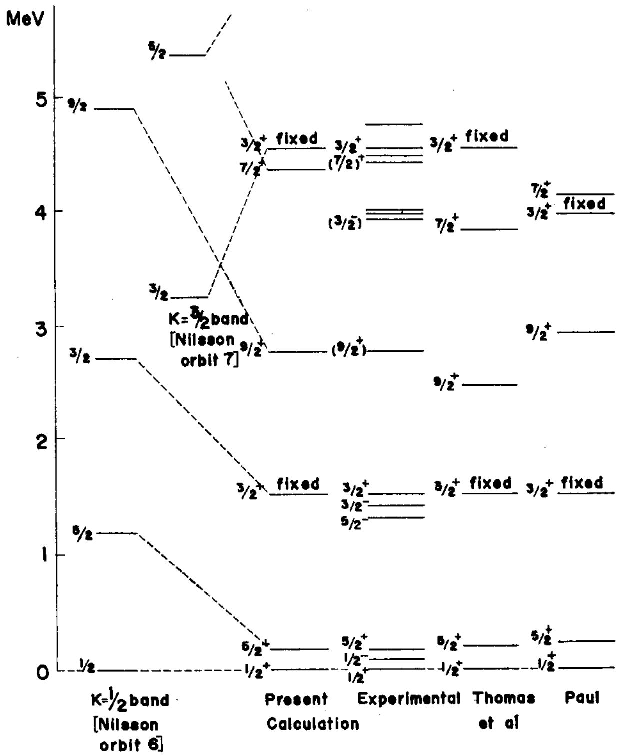

Fig. 2. Energy Levels of ^{19}F.
(columns 1 and 2) rotational band spectra of $K=1/2$ and $K=3/2$,
(column 3) present calculation,
(column 4) observed,
(column 5 and 6) calculated by Thomas *et al* and Paul.

The level order for a rotational band K is given by

$$E_K(I) = E_K^{(0)} + E_K^{(1)}\{I(I+1) + \delta_{K,1/2}(-)^{I+1/2}(I+\tfrac{1}{2})\,a\} \qquad (1)$$

where the moment of inertia term $E_K^{(1)}$ and the decoupling parameter a depend upon the nuclear configuration in some way. However, these K and $K+1$ bands are mixed according to the rotation particle coupling (RPC) effect, and the non-vanishing matrix element for mixing is

$$\langle IK|I_{\pm}|IK\pm1\rangle = \sqrt{(I\mp K)(I+K+1)}\,. \qquad (2)$$

The resulting energy spectrum will be

$$E(I) = \tfrac{1}{2}\{E_K(I)+E_{K+1}(I)\} \pm \tfrac{1}{2}\sqrt{\{E_{K+1}(I)-E_K(I)\}^2 + 4A_K^2(I-K)(I+K+1)} \qquad (3)$$

where

$$A_K = \left| \left\langle K \left| \frac{\hbar^2}{2I} \sum_{\text{particles}} j \right| K+1 \right\rangle \right| . \tag{4}$$

Thus the state of the same spin in these bands, that is, $3/2^+$, $5/2^+$, $7/2^+ \cdots\cdots$ states, will be pushed apart but the ground state $I=K=1/2^+$ is not affected because it has no corresponding partner in the $K+1$ band.

The $E^{(1)}_{1/2}$ and $E^{(2)}_{3/2}$ values for ^{19}F have been usually taken equal. However in the present calculation, they are chosen as

$$E^{(1)}_{1/2} = 0.301 \text{ MeV}, \quad E^{(1)}_{3/2} = 0.314 \text{ MeV}$$

and the decoupling parameter a is given as 1.85. These values would be reasonable as described later. The final result is shown in Fig. 2, where the 1.56 and 4.57 MeV levels of $3/2^+$ are fixed. The calculatetd states by Paul[3] and Thomas *et al*[9] are again presented in the figure.

3. Discussion

The calculation by Paul has been performed by requiring that (1) the pushed down $3/2^+$ state is fixed at the observed 1.56 MeV level and (2) the pushed up $3/2^+$ state is assumed to be at 4 MeV. On the contrary, Thomas *et al* have fitted these levels at the experimental 1.56 and 4.57 MeV states respectively. Both calculations lead to some discrepancies in fitting other levels, as seen in Fig. 2. This would be explained in the following way.

Paul's $3/2^+$ state at 4 MeV is now undecisive in its spin. Their $E^{(1)}_{1/2}$ and $E^{(1)}_{3/2}$ values were equal, that is, 0.3 MeV by Paul and 0.27 MeV by Thomas *et al*, but the reason of equality is ambiguous. Since K is the projection of the total angular momentum on the nuclear symmetry axis, the moment of inertia term $E^{(1)}_K$ would be somewhat different for different K's. For instance, those for the $K=1/2^-$ and $5/2^-$ bands in ^{169}Yb are 11.5 and 12.5 keV, repsectively. The values for the $K=1/2^+$ and $3/2^+$ bands in ^{159}Tb are fixed as 11.9 and 11.5 keV, respectively. Therefore the present choice of 0.301 and 0.314 MeV for ^{19}F seems very reasonable. The decoupling parameter a can range from 1.83 to 2.23 according to the calculation by this model.

The 2.79 MeV level is the pushed down state of $I=9/2$ in the $K=1/2$ band and its spin was recently assigned as $9/2^+$ by Olness *et al*[10] from the β-decay of ^{19}O. The pushed up $5/2^+$, $7/2^+$, $9/2^+$ levels may be predicted. However, referring to the non-collective levels of ^{18}O and ^{20}Ne, the pushed up states may appear in the higher region where many complex states are found.

From the point of view of the collective model, E2 transitions within a rotational band are expected to be enhanced. In fact, the lifetimes of the lower $5/2^+ \rightleftarrows 1/2^+$ E2 transition which have been observed by the Coulomb excitation and other experiments are appreciablly shorter than the single particle estimate, though the present $5/2^+$ state is a pushed down state resulting from the band-mixing considered above.

The present calculation explains the low-lying and positive parity states more satisfactory than others but a discrepancy still remains. This may be improved by introducing some other additional correction terms to Eq. (1). However such procedure is not so significant because the terms have little physical meaning.

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